IPRM 2001, Nara, Japan

# Integration of heterostructure bipolartransistor and electroabsorption waveguide modulator based on a multifunctional layer design for 1.55μm

T. Reimann*, M. Schneider#, P.Velling*, S. Neumann*, M. Agethen*, R.M. Bertenburg*, R. Heinzelmann#, A. Stöhr#, D. Jäger#, F.-J. Tegude*

* Solid-State Electronics Dept., University Duisburg, # Fachgebiet Optoelektronik, Universität Duisburg
Zentrum für Halbleitertechnik und Optoelektronik (ZHO), Fachbereich Elektrotechnik, Gerhard-Mercator-Universität Duisburg, Lotharstr. 55, 47057 Duisburg, Germany, reimann@hlt.uni-duisburg.de

## Abstract

There is a continuous development in the monolithic integration of electronic and optical devices to add functionality and improve performance. For a short review on heterostructure bipolar transistors (HBTs) combined with lasers or photodetectors see e.g. [1]. The following work focusses on the combination of HBTs and electroabsorption waveguide modulators (EAMs). One way is to stack the two layer structures for each device on top of each other [2], resulting in two separate devices, which have to be processed one after the other. A different possibility merges the modulator into the layer stack of the HBT. This was done for a GaAs-based HBT, where a carrier-injected optical intensity modulator is implemented in the base layer [3]. In our InP-based approach we insert the waveguide into the collector region and use the electric field for band gap changes in the guide material for modulation (Franz-Keldysh effect, FKE). The resulting layer stack enables a new type of merged device (HBT-EAM). This corresponds to a modulator with an integrated amplifier and therefore the demands on a driver circuit can be reduced. Additionally, optical waveguides, modulators and bipolar transistors can be processed as single devices from the same layer.

If the HBT of the merged device is operated in the common emitter configuration with load resistance it is able to switch the build-in EAM (Fig. 1). When the transistor is in off-state, the base-collector diode is reverse biased, which results in a high electric field inside the collector, i.e. in the region of the optical waveguide, thus the optical power is absorbed. If the base current is increased, the tranistor switches to the on-state, which reduces the electric field inside the waveguide, therefore the absorption coefficient decreases and the waveguide gets transparent.

To optimize HBT and EAM operation design-rules include various trade-offs. Cladding layers have to be chosen thick enough not to degrade the HBT-collector. Furthermore low background doping of the upper cladding/collector improves the electric field in the guide, but declines transistor operation, which can be avoided by the addition of a composite collector at the base/collector transition. The choice of high band gap material in the upper cladding, needed for waveguiding, also improves breakdown voltage $BV_{CB}$.

The resulting layer-system is shown in Fig. 2. The common design of a emitter-up HBT is adapted in the collector region where optical cladding layers were added to get an optical waveguide. The structure is grown on s.i.-InP by LP-MOVPE as follows: First the n-doped sub-collector (InP:Si) was grown, which in combination with the substrate also acts as the lower cladding layer. It follows the intrinsic collector made of InGaAsP ($\lambda$=1.48μm) as the optical waveguide core and an InP layer as the upper cladding of the optical waveguide. The stack is finished with base ($p^+$-InGaAs:C) and emitter (n-InP) layers.

From this layer structure isolated transistors and modulators as well as merged devices were processed using optical lithography with conventional wet-chemical etching and metallization steps (Fig. 3). The HBT's with an emitter area of 3*10μm² show collector currents of 5mA and current gains up to 50 with collector-emitter voltages above 6V. High-frequency values are $f_T$=30GHz and $f_{max}$=25GHz. Mesa waveguide modulators (EAM's) with 200μm length and 9μm width exhibit a 3dB cut-off frequency of 10GHz (at 1.55μm). The DC output characteristic of a HBT-EAM (in HBT-configuration) is plotted in Fig. 4 and RF-values are $f_T$=23GHz and $f_{max}$=20GHz. Optoelectronic DC-measurements of a HBT-EAM (in common-emitter configuration) are illustrated in Fig. 5. The device achives an optical contrast of more than 4dB at a base current switched from 6μA to -2μA at $V_{CC}$=10V. RF-measurements are currently in progress.

[1] S. Chandrasekhar, "Optoelectronic system integration using InP-based HBTs for lightwave communications", *Solid-State Elec.*, vol. 41, 1997, p.1413.

[2] M.T. Camargo Silva, J.E. Zucker, L.R. Carrion, C.H. Joyner, A.G. Dentai, "Growth Optimization for p-n Junction Placement in the Integration of Heterojunction Bipolar Transistors and Quantum Well Modulators on InP", *IEEE J. Selected Topics in Quantum Elec.*, vol. 6, 2000, p. 26

[3] Y. Okada, K. Tada, "Application of bipolar transistor structures to optical waveguide modulators and switches", *J. Appl. Phys.*, vol. 69, 1991, p. 73

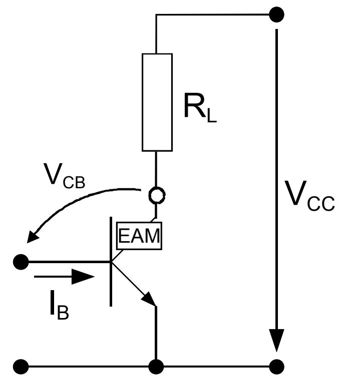


Fig. 1: HBT-EAM in common emitter configuration. The EAM is implemented in the HBT-collector and is driven according to $V_{CB}$.

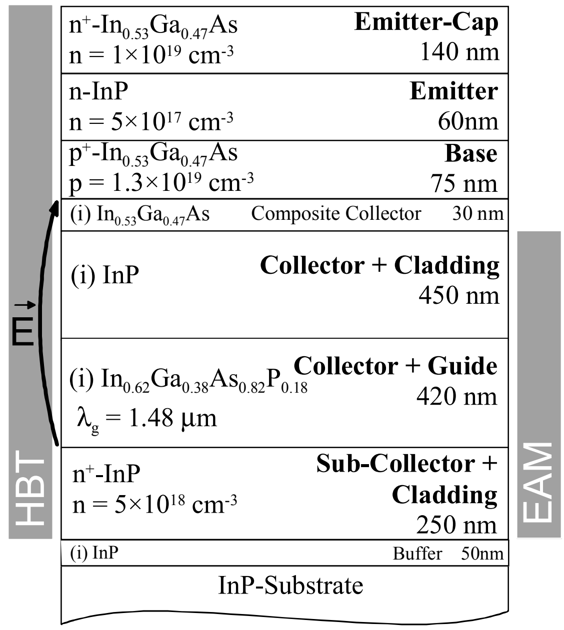


Fig. 2: Multifunctional layer-stack, which combines HBT and EAM.

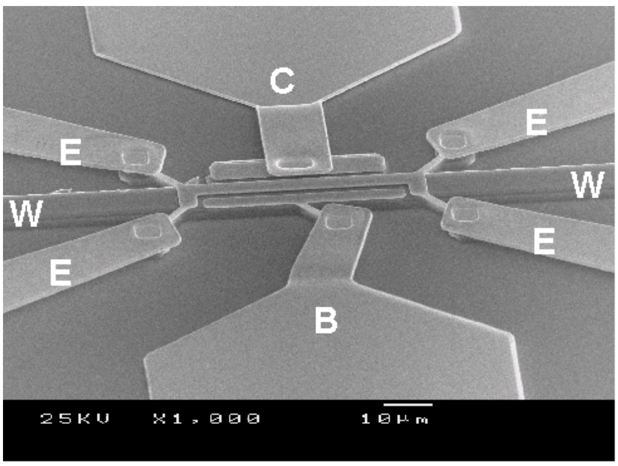


Fig. 3: SEM-graph of a HBT-EAM in a four mesa process; "W" denotes the waveguide.

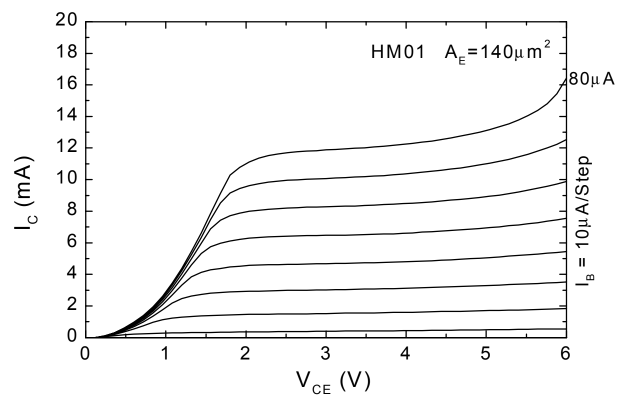


Fig. 4: DC output characteristic of a HBT-EAM. $V_{CE}$ is plotted up to 6V. $BV_{CB}$ is about 9V.

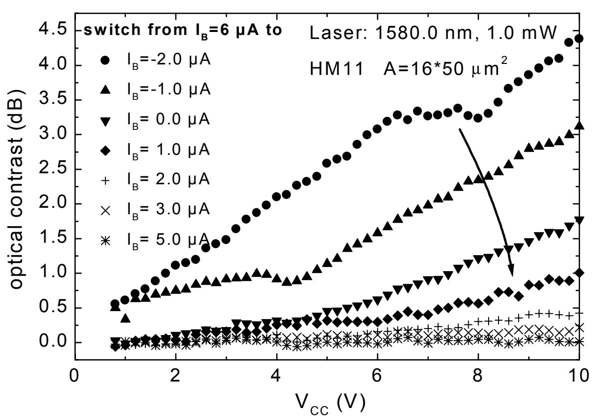


Fig. 5: Optical contrast of a HBT-EAM in common-emitter configuration. The tranistor is switched off completely only with small negativ $I_B$ due to absorption of light.